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Old RO membranes: solutions for reuse

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ABSTRACT

The overall objective of the present work was to estimate the degradation level of old reverse osmosis (RO) membranes in terms of permeability and salt rejection, along with their potential reuse as ultrafiltration (UF) membranes after NaOCl oxidation at 62,500 ppm for 3 h. Detailed study of old RO membrane materials deconstruction has also resulted in recommendations in their reuse as geotextile, mouse pad, support for children drawings, protection to snake attack, and aromatic wall in familial kitchen; all being alternatives solutions to incineration. At the end of the work, 95% of the old RO membrane materials were recycled.

Keywords: Reverse osmosis; Nanofiltration; Ultrafiltration; Membrane ageing; Membrane reuse; Module deconstruction

1. Introduction

Ageing in reverse osmosis (RO) plants can be caused by a number of common foulants such as inorganic scales, organic matter, and biofilm that are eliminated by high frequency chemical cleaning or defaults appearing during their use [1].

When RO membranes lose their desalination properties (salts rejection lower than 99%), they are usually incinerated. But others choice can be considered, as reported previously by a second life in secondary or tertiary wastewaters treatment [2–5]. Furthermore, old RO membranes should be reused as nanofiltration (NF) for seawater pre-treatment, for selective demineralization of brackish waters with excess fluoride ions or for the elaboration of isotonic/hypertonic salty solutions dedicated to thalasssotherapy activities [6–11].

For all RO units in the world (51% of the installed capacity, Fig. 1) we can correlate mass of old RO module generated by the units with the growth of desalination market (Fig. 2).

An exponential increase was observed for both parameters and the projections in 2020 predicted 124 million m^3/d for desalination capacity in the world and in the same time an annual mass of old RO module product of 12.000 t, as reported in Fig. 2.

The overall objective of our actual research programs is to conduct membrane autopsy on old seawater RO spiral wound module in order to estimate the level of their ageing and then envisage their reuse, as recently reported [7].

The life cycle electricity consumption is the total electricity consumed during the treatment plant construction and operation phases. Electricity

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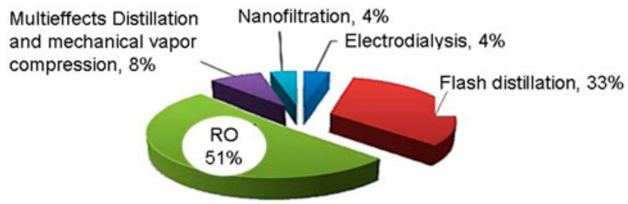

Fig. 1. Installed capacity by process (IDA Desalination Yearbook, 2010).

consumption at the potable water plant is calculated using site measurements and the previously described equipment models. Electricity consumption for off-site chemicals production is calculated using Ecoinvent data-sets. Electricity consumption for plant construction is calculated using Ecoinvent data-sets and is found to be negligible in comparison with the electricity consumption for plant operation, as reported elsewhere [12].

The life cycle electricity consumption of the RO plant is about 4.6 kWh/m^3 of potable water, as reported in the Fig. 3. Electricity consumption for the RO process represents most of the life cycle electricity consumption with 84% of total electricity consumption. Concerning the electricity cost of membrane renewal, we observed a very low cost, identical between RO and NF with 0.02 kWh/m^3.

Furthermore, in a near future we can hypothesis that the environmental cost will be estimated not negligible regarding the dramatic increase of old RO module accumulated everywhere in the world.

2. Experimental

2.1. Membranes and modules

The RO membranes under study are thin-film composite membranes built up of two layers—a thin polyamide film denoted active surface and a large mesoporous polysulfone denoted support layer. We extracted flat-sheet membranes from spiral wound modules (Fig. 4) (commercial reference SW30-400) purchased by Filmtec, Dow Chemical Company (US)) and used in Australia and Israel. All membranes were used after a complete elimination of the preservatives by intensive rinsing with UP water until the conductivity of the permeate remained below UP water conductivity (<1 μS cm^{-1}) and total organic carbon (TOC) (<3 mg/L).

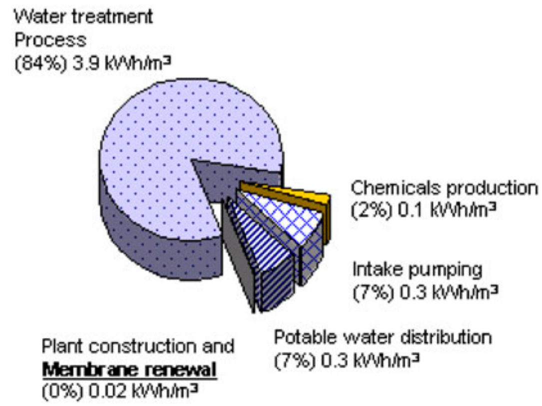

Fig. 3. Life cycle electricity consumption in RO (4.6 kWh/m^3).

2.2. Bench-scale pilot plant

A flat sheet laboratory NF/RO setup consisting of a flat sheet cross flow module (Osmonics, Module SEPA CFII, USA), with a membrane area of 138 cm^2, was used in total recycle mode. The total volume of the system was 5 L. The feed tank was equipped with a temperature control system maintained to 22˚C. A gear pump (Wanner GP, US) with variable speed has been used to circulate the feed solution through the module. Two valves were installed at the concentrate outlet and the feed inlet to adjust the trans-membrane pressure and the volumetric flow rate (Fig. 4).

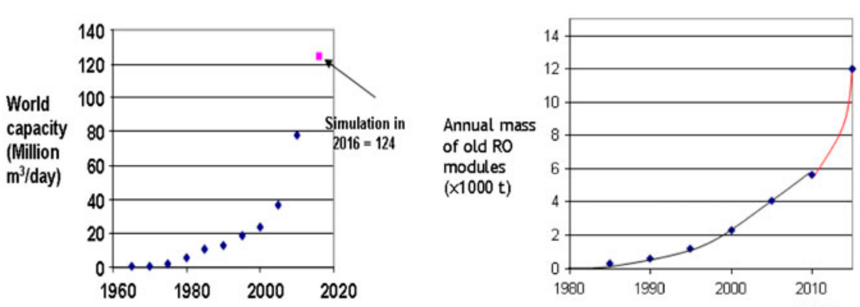

Fig. 2. World desalination capacity and mass of old RO modules vs. year (from [7]).

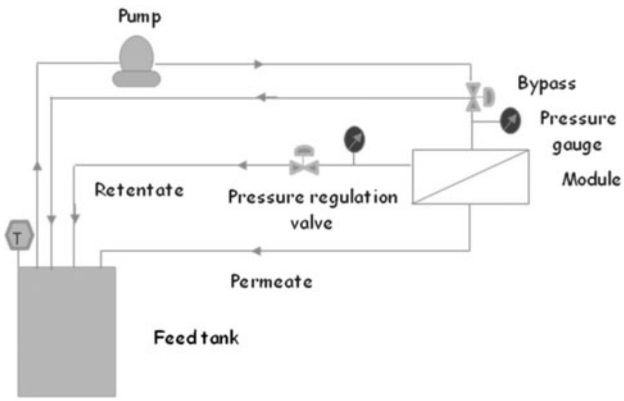

Fig. 4. Schematic representation of the flat sheet RO/NF bench scale setup.

All work was done under low flow yield ratio (<1%) and a tangential flow rate of 0.16 m s^{-1} with a tangential Re number between 300 and 400, similar hydraulic conditions encountered in spiral wound modules. During our experiments we have limited the concentration polarization by using dilute solutions and high flow rate. The applied trans-membrane pressures were in the range of 0–30 bar.

Permeated solutions were recycled during the runs expect for samples withdrawn for the calculation of retention, denoted R, according to:

$$R = 1 - \frac{C_p}{C_o} \tag{1}$$

where C_p and C_o are the concentrations in the permeate and feed solutions, respectively. The salts solutions were analyzed by a conductometer (PHM210, from Radiometer Analytical, France) after standardization for each salt and concentration. Furthermore, under our hydraulic conditions, we can consider that R is not influenced by a concentration polarization layer. Pure water flux through the membranes can be described by the following Eq. (1):

$$J_v = L_P \cdot (\Delta P - \Delta \Pi) \tag{2}$$

with J_v the flux through the permeate (in L h^{-1} m^{-2}), ΔP the trans-membrane pressure applied (in bar), $\Delta \Pi$ the trans-membrane osmotic pressure (in bar), and L_p the hydraulic permeability of the membrane (in L h^{-1} m^{-2} bar^{-1}).

A picture of the assembled experimental set-up is shown in Fig. 5.

Preliminary, filtration experiments with ultra pure water and synthetic brackish water (NaCl at 0.1 M for a total salinity near 6 g/L) were carried out to determine virgin and old membranes permeabilities. We used a trans-membrane pressure range of 0–35 bar

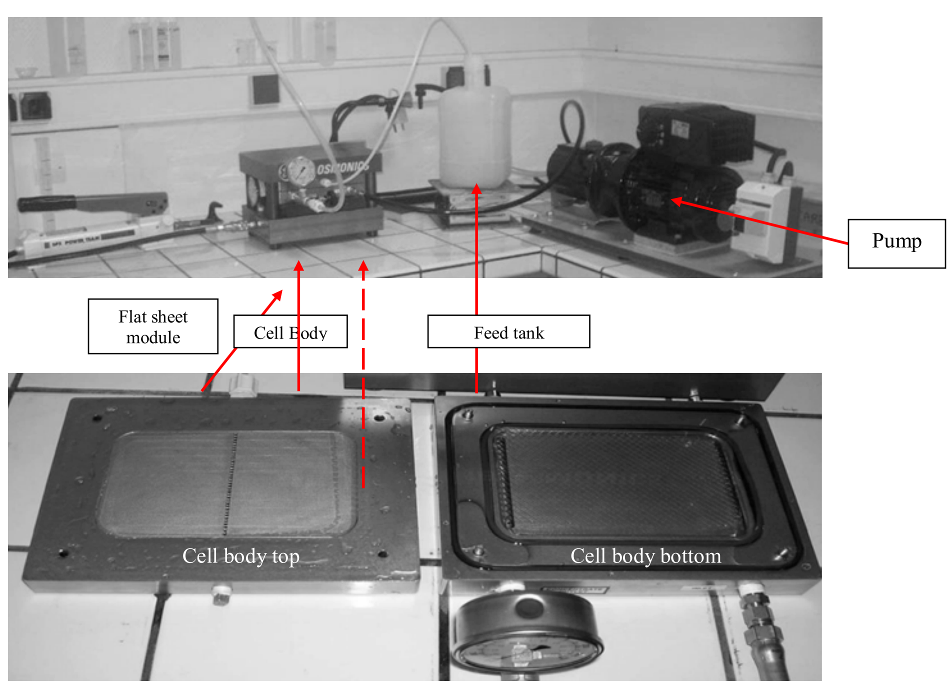

Fig. 5. SEPA CFII membrane element cell flow sequence.

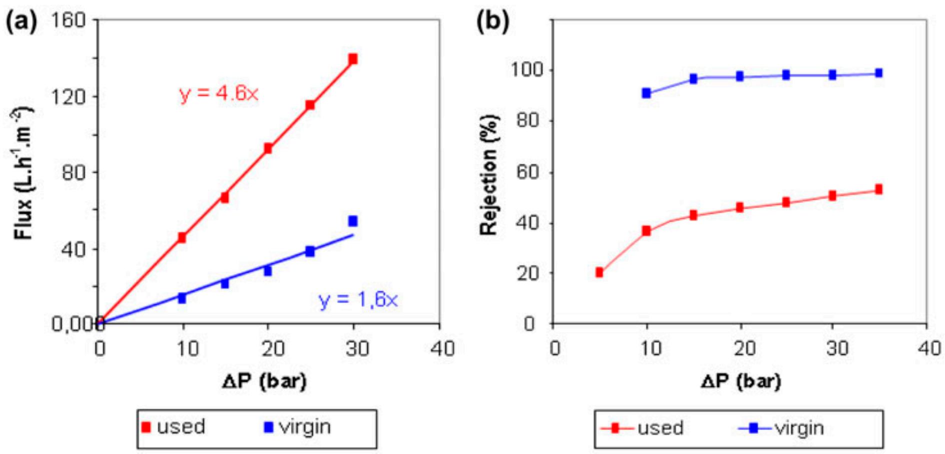

Fig. 6. (a) Evolution of the flow rate vs. trans-membrane pressure to UPW for the virgin RO and old RO membranes; (b) Rejections vs. trans-membrane pressure for virgin and old RO membranes (NaCl solution 6 g/L, pH 6.6, and $T = 22$°C).

and a maintained temperature of 22°C. For each pressure the permeate volume with time was measured in order to calculate the permeate flow rate and determine the hydraulic permeability in conformity to Eq. (2).

2.3. Solutions

The NaCl, NaOCl, $KMNO_4$, and NaOH solutions used were of analytical grade from Aldrich (France) and used as received. UPW is delivered by a Elga water system (classic UV–UF system). The quality of the UPW was as follows: conductivity 1 µS/cm, pH 6.5, and TOC <3 mg/L.

3. Results and discussion

3.1. Hydraulic permeability and salt rejection determinations

The experimental data of NaCl rejection vs. trans-membrane pressure (ΔP), for virgin and old RO membranes are reported in Fig. 6(a).

For the virgin membrane the membrane permeability is 1.6 L h^{-1} m^{-2} bar^{-1}, as for the old one the permeability is 4.8 L h^{-1} m^{-2} bar^{-1}. Concerning the rejections to NaCl solution the data are reported in the Fig. 7. For the virgin membrane, the rejections are higher than 90%, from 10 to 30 bar. In the case of the old RO membrane, we observed lower rejections which comprised between 20–50% in the trans-membrane pressure range of 5–35 bar. The rejections results completed well the hydraulic permeabilities reported, illustrating very well the membrane ageing.

Fig. 7. Gravity filtration design made in Australia.

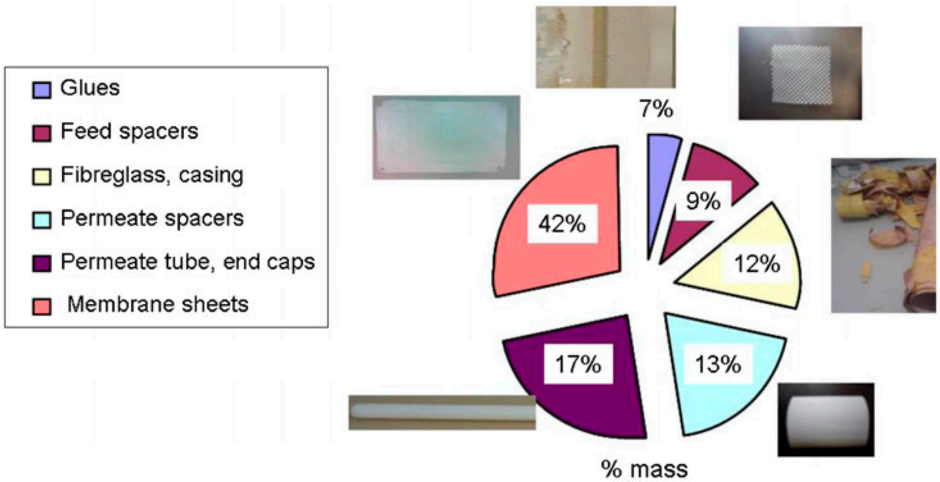

Fig. 8. Mass (in %) of all materials constituting old RO modules.

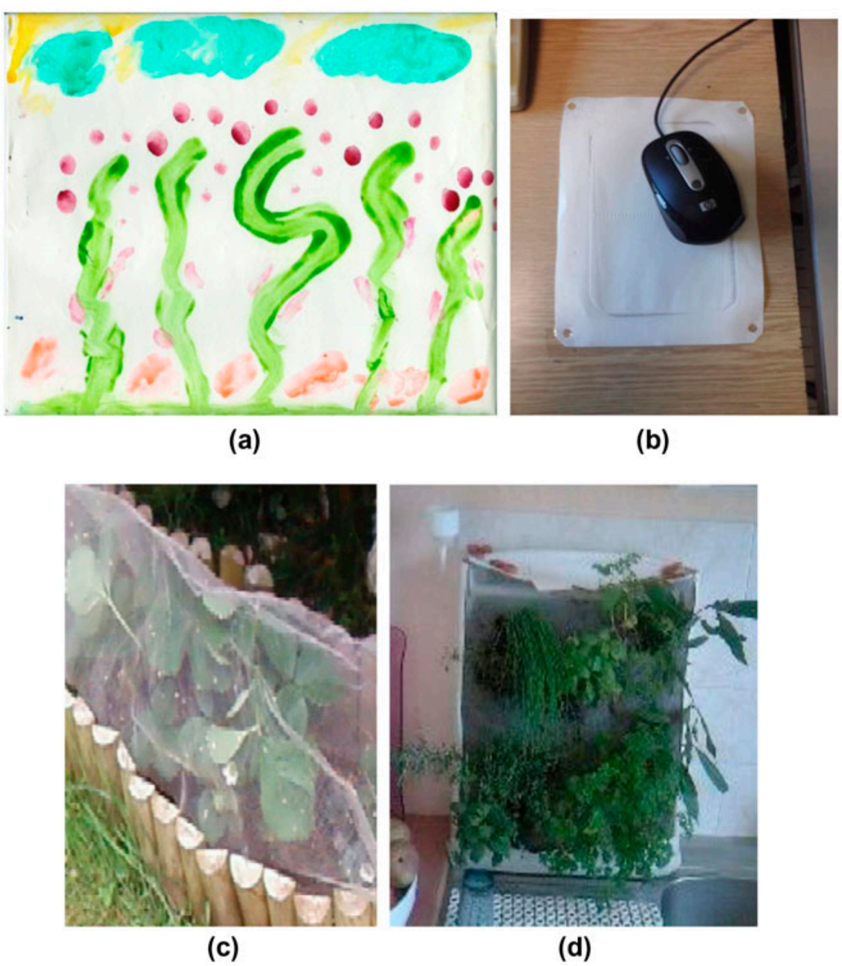

Fig. 9. Few applications of old RO modules materials.

3.2. Hydraulic permeability and salt rejection determinations for different chemical treatments of the old RO membrane in order to standardize the chemical attack

As reported very recently [13] the best chemical treatment for old RO membrane was observed with NaOCl at 62,500 ppm for 6 h, the permeability obtained was 180 $L\,h^{-1}\,m^{-2}\,bar^{-1}$. This hydraulic permeability is equivalent in membrane molecular weight cut-off to a10 kDa ultrafiltration membrane. The best interest in this new approach in comparison to Veza's work [4] is the standardization of the chemical attack and the elaboration of a new UF membrane usable to sterilize surface water.

3.3. Applications in gravity filtration

Previously work proposed to reuse membrane for a second life after chemical elimination of the active layer of the membrane inside the module for the tertiary treatment of secondary treated wastewaters. Furthermore old RO membranes should be reused as NF for seawater pre-treatment or forward osmosis processes, for selective demineralization of brackish waters with excess of fluoride ions, for the elaboration of isotonic/hypertonic salty solutions for thalassotherapy centers or also for coral growth studies [1–12,14].

One new application dedicated to this new UF 10 kDa membrane elaborated is the gravity filtration of surface water dedicated to countries with economical difficulties and/or isolate sites everywhere in the world (Fig. 7), as very recently reported [13].

3.4. Membrane deconstruction and applications of old RO membrane materials

After membrane reuse one time, two times, or more what happened?

Actually the incineration is a rule. But incineration must be forbidden due to the dramatic consequences to waste streams and by the fact that RO modules are composite materials generating complex streams to treat as illustrated in Fig. 8. To envisage reuse of those old RO membranes should create new jobs dedicated to the green chemistry and then will participate to the protection of Earth atmosphere.

Old RO permeate spacers as geotextile (as elsewhere reported, [2]), membrane for children drawings (Fig. 9(a)), mouse pad (Fig. 9(b)), feed spacers to prevent snake attack to strawberry plants (Fig. 9(c)), and membrane/concentrate spacer and permeate tube to elaborate a vegetalize wall with aromatic herbs dedicated to a kitchen have been proposed in the present work as alternatives solutions to incineration.

We are working with membranes processes which are considered as green processes that allow us to use greater amounts of recycled materials in the place of incineration. Then, environmental impact assessment will soon become a compulsory phase in future potable water production projects using RO membranes.

At the end of our work we have estimated that 95% of the old RO membrane materials have been recycled.

4. Conclusion

The overall objectives of the present work were to estimate the level degradation of old RO membranes in terms of permeability/salt rejection and their reuse as UF membranes after NaOCl oxidation at 62,500 ppm for 6 h. A new UF 10 kDa membrane was elaborated. The last part have shown how old RO membrane materials can be reused as geotextile, mouse pad, support for children drawings, strawberry plants protection to snake attack, and aromatic wall in familial kitchen, alternatives solutions to incineration. At the end of the work 95% of the old RO membrane materials were recycled. In works life cycle assessment method will be applied to old RO modules in order to compare incineration alternatives solutions exposed in the present work. Furthermore, the same approach could be applied to old NF membranes.

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Symbols

ΔP	—	trans-membrane pressure, in bar
$\Delta \Pi$	—	trans-membrane osmotic pressure, in bar
C_o	—	the concentrations in the feed solution, in g/L
C_p	—	the concentrations in the permeate, in g/L
J_v	—	the solvent flow, in $L\,h^{-1}\,m^{-2}$
L_p	—	hydraulic permeability of the membrane to ultrapure water, in $L\,h^{-1}\,m^{-2}\,bar^{-1}$
R	—	salt rejection, in %

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